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# RESEARCH MEMORANDUM

## GUST-TUNNEL INVESTIGATION OF A DELTA-WING MODEL WITH THE LEADING EDGE SWEPT BACK 60°

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# GUST-TUNNEL INVESTIGATION OF A DELTA-WING MODEL WITH THE LEADING EDGE SWEPT BACK 60°

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## SUMMARY

A gust-tunnel investigation of a delta-wing model with the leading edge swept back 60° has indicated that the gust load is greater than would be predicted by using a slope of the lift curve determined from steady-flow force tests. The use of a slope of a lift curve derived from simple aspect-ratio considerations resulted in a good estimate of the load.

## INTRODUCTION

Gust-tunnel investigations of the loads on swept wings (references 1 to 3) have indicated that the slope of the lift curve determined from steady-flow force tests is not applicable in a gust but rather that one dependent on the slope of the lift curve of an equivalent straight wing and on the cosine of the angle of sweep would be applicable. In addition, the results for the swept wings showed that strip theory could be used to estimate the effect of gradual penetration into a gust. Since the delta wing might be considered a special form of a swept wing, it appeared possible that a slope of the lift curve other than that determined from steady-flow force tests would apply in a gust. A simple relationship for determining the applicable slope of the lift curve, however, was not immediately apparent. Accordingly, an investigation has been carried out in the Langley gust tunnel with a delta-wing model having the leading edge swept back 60°. The purpose of the investigation was to determine the magnitude of the gust load and to determine if steady-flow aerodynamic coefficients could be used successfully in its prediction. This paper presents the results of the investigation.

## APPARATUS AND TESTS

A line drawing of the 60° sweptback delta-wing model is shown in figure 1 and a photograph of the model is shown as figure 2. The characteristics of the model and the test conditions are given in table I. The airfoil was an NACA 65-006 section at the root and was tapered to an NACA $65_1$-012 section at a point 1.5 inches from the tip. The construction of the model was such that it could be considered a rigid body for the tests. An accelerometer was mounted under the forward part of the fin at the center of gravity. Two lights were mounted on the model for the measurement of pitch in free flight.

The gust tunnel and its equipment are described in reference 4. The gust profiles of the sharp-edge gust and 6.5-chord-gradient gust are shown in figure 3 as the ratio of the local gust velocity to the average maximum gust velocity as a function of mean chords of penetration.

The tests consisted of eight flights through the sharp-edge gust and seven flights through the gust with the 6.5-chord gradient distance. Measurements of forward velocity, gust velocity, normal-acceleration increment, and pitch-angle increment were made for each flight.

Force tests were conducted in the Langley free-flight tunnel for the purpose of determining the free-flight trim condition. A steady-flow slope of the lift curve was determined from the data and is included in table I.

## PRECISION

The measured quantities are estimated to be accurate within the following limits for any test or run:

| | |
|---|---|
| Normal-acceleration increment, $\Delta n$, g units . . . . . . . . . . . . . | $\pm 0.05$ |
| Forward velocity, feet per second . . . . . . . . . . . . . . . . . . | $\pm 0.5$ |
| Gust velocity, feet per second . . . . . . . . . . . . . . . . . . . . | $\pm 0.1$ |
| Pitch-angle increment, degrees . . . . . . . . . . . . . . . . . . . . | $\pm 0.1$ |

## RESULTS AND DISCUSSION

The records of all flights were evaluated to obtain histories of the normal-acceleration increment and pitch-angle increment during traverse through the gust. Representative test results are shown in figures 4(a) and 4(b). The maximum acceleration increment was determined from the time history of each test flight. Since minor variations in forward speed and gust velocity are obtained from flight to flight, the maximum acceleration increments were corrected to a forward speed of 88 feet per second and a gust velocity of 10 feet per second on the assumption that the acceleration increment is directly proportional to forward speed and gust velocity. In addition, the corrected data were further reduced to the values for zero pitching motion by the approximate method of reference 1. The values of the maximum acceleration increment for each flight as corrected for forward speed and gust velocity together with the values reduced to zero pitching motion are given in table II. The average values for both gust shapes were determined from the data and are included in the table.

Examination of the pitch-increment curves of figure 4 shows that the delta-wing model initially pitches up on entering the gust and soon afterward pitches down. The effect of this sequence of pitching motion is evident when a comparison is made of the effect of pitch on the average maximum values of acceleration increment in each of the gust shapes. (See table II.) In the sharp-edge gust, where the maximum acceleration increment is obtained quickly, the initial pitching-up motion increases the load a small amount. In the gust with the 6.5-chord gradient distance, however, the maximum acceleration increment occurs after the model pitches down so that the pitching motion decreases the load about 5 percent.

The rapid pitching motion of the model as it passed through the gusts and the reversal of the effect of pitching motion on the maximum accelerations which occurs for the change in gust shape from sharp edge to 6.5-chord gradient indicate that the pitching motion of the delta-wing model is probably quite sensitive to the center-of-gravity position. Further investigation will be necessary, however, before quantitative predictions can be made of the change in load with center-of-gravity position. The initial positive pitching motion of the model is believed to be a result of the gradual penetration of the delta wing into the gusts. The effect of penetration on the pitching motion in the present case, however, does not appear as great as that on the swept wings of references 1 to 3.

Prediction of the gust load was made with the use of equation (2) of reference 1. The slope of the lift curve was that determined from force tests and the unsteady-lift functions were those for infinite aspect ratio where the unsteady-lift function for penetration of the gust was modified by strip theory to account for the gradual penetration of the delta wing into the gust. The results of this calculation are compared with the experimental results reduced to zero pitching motion in table III. The comparison shows that use of the slope of the lift curve derived from force-test measurements in the calculations results in an underestimation of the gust load of some 20 to 25 percent.

In order to investigate the discrepancy between the calculated and experimental results, three additional calculations for the delta wing were made with only the slope of the lift curve being changed and, for comparison, a calculation was made for a straight wing of the same aspect ratio. The lift-curve slopes used in the calculations for the delta wing were: (1) a slope of 2.61 per radian obtained from lifting-surface-theory calculations for a 60° delta wing, (2) a slope of 3.66 per radian predicted from the work of Jones based on Munk's airship theory (reference 5) for low-aspect-ratio pointed wings, and (3) a slope of 3.23 per radian obtained from the simple aspect-ratio relation $6A/(A + 2)$ which has been used successfully for determining slopes for the prediction of gust loads on straight wings (reference 4). The slope of the lift curve of 3.23 per radian was also used in the calculation for the straight wing together with the unmodified unsteady-lift function for penetration into the gust. The results of these four calculations are included in table III.

It is apparent from examination of table III that only two of the calculations agreed well with the experimental results. Use of the lifting-surface theory underestimated the experimental results by 15 to 20 percent; whereas use of the slope from airship theory overestimated them by about 8 percent. The best agreement was obtained when the lift-curve slope, derived from the simple formula $6A/(A + 2)$, was used with either unsteady-lift function. If the assumption is made that other factors such as the choice of the unsteady-lift function are correct, the effect of the gradual penetration of the delta wing into the gust is indicated to be small. On the basis of these results, therefore, it is implied that the gust load on a 60° delta wing can be predicted by use of the slope of the lift curve of 3.23 per radian derived from the formula $6A/(A + 2)$ even when the effect of the gradual penetration of the delta wing into the gust is disregarded.

Although the implications of the preceding paragraph are in agreement with the experiment, much doubt still exists as to what the real situation might be. The results presented indicated that the loads may be predicted equally well by methods having different concepts. It is apparent, therefore, that the basic principles are not fully understood and additional information will be needed before extension of the results of this paper can be made for the calculation of the gust load on delta wings having apex angles other than 60°.

## CONCLUDING REMARKS

A gust-tunnel investigation of a delta-wing model with the leading edge swept back 60° has indicated that the use of the slope of the lift curve, determined by steady-flow force tests in gust-load calculations, underestimated the gust load by 20 to 25 percent. Further study showed that a good estimate of the gust load for this wing was obtained through the use of a slope of the lift curve derived from the simple aspect-ratio relation $6A/(A + 2)$. Extension of these results to other delta wings with different apex angles, however, does not appear warranted at this time. Additional investigation will be necessary to establish the importance of the center-of-gravity position on the loads induced by the pitching motion of the delta wing in a gust.

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## REFERENCES

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2. Reisert, Thomas D.: Gust-Tunnel Investigation of a Wing Model with Semichord Line Swept Back 30°. NACA TN 1794, 1949.

3. Pierce, Harold B.: Gust-Tunnel Investigation of a Wing Model with Semichord Line Swept Back 60°. NACA TN 2204, 1950.

4. Donely, Philip: Summary of Information Relating to Gust Loads on Airplanes. NACA Rep. 997, 1950. (Formerly NACA TN 1976.)

5. Jones, Robert T.: Properties of Low-Aspect-Ratio Pointed Wings at Speeds below and above the Speed of Sound. NACA Rep. 835, 1946. (Formerly NACA TN 1032.)

# TABLE I

## CHARACTERISTICS OF THE MODEL AND TEST CONDITIONS

| | |
|---|---|
| Weight, lbs | 11.7 |
| Wing area, sq ft | 6.92 |
| Wing loading, lb/sq ft | 1.69 |
| Span, ft | 4.00 |
| Mean geometric chord measured in plane parallel to plane of symmetry, Area/Span, ft | 1.73 |
| Aspect ratio, A | 2.33 |
| Root chord, ft | 3.46 |
| Slope of the lift curve determined by steady-flow force tests, per radian | 2.4 |
| Center-of-gravity position, percent mean geometric chord | 0 |
| Gust velocity, fps | 10 |
| Forward velocity, fps | 88 |
| Pitching moment of inertia, slug-ft$^2$ | 0.286 |

TABLE II

MAXIMUM VALUES OF ACCELERATION INCREMENT FOR EACH FLIGHT CORRECTED FOR FORWARD SPEED AND GUST VELOCITY AND REDUCED TO ZERO PITCH

| Gust shape | Flight | Corrected experimental $\Delta n_{max}$ (g units) | Corrected experimental $\Delta n_{max}$ reduced to zero pitch (g units) |
|---|---|---|---|
| Sharp edge | 1 | 1.29 | 1.25 |
| | 2 | 1.28 | 1.26 |
| | 3 | 1.36 | 1.32 |
| | 4 | 1.25 | 1.23 |
| | 5 | 1.25 | 1.22 |
| | 6 | 1.28 | 1.26 |
| | 7 | 1.34 | 1.30 |
| | 8 | 1.35 | 1.30 |
| | Average | 1.30 | 1.27 |
| 6.5-chord gradient | 1 | 1.01 | 1.06 |
| | 2 | 1.03 | 1.07 |
| | 3 | 1.06 | 1.10 |
| | 4 | 1.02 | 1.09 |
| | 5 | .98 | 1.04 |
| | 6 | 1.00 | 1.07 |
| | 7 | 1.01 | 1.07 |
| | Average | 1.02 | 1.07 |

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TABLE III

COMPARISON OF EXPERIMENT AND CALCULATION

| Gust shape | Corrected experimental $\Delta n_{max}$ reduced to zero pitch (g units) | Calculated $\Delta n_{max}$ (g units) | | | | |
|---|---|---|---|---|---|---|
| | | Delta wing | | | | Straight wing |
| | | Measured lift-curve slope of 2.4 | Lifting-surface-theory lift-curve slope of 2.61 | Airship-theory lift-curve slope ($\pi A/2$) of 3.66 | Lift-curve slope ($6A/(A + 2)$) of 3.23 | Lift-curve slope ($6A/(A + 2)$) of 3.23 |
| Sharp edge | 1.27 | 0.95 | 1.02 | 1.35 | 1.21 | 1.27 |
| 6.5-chord gradient | 1.07 | .86 | .91 | 1.15 | 1.06 | 1.10 |

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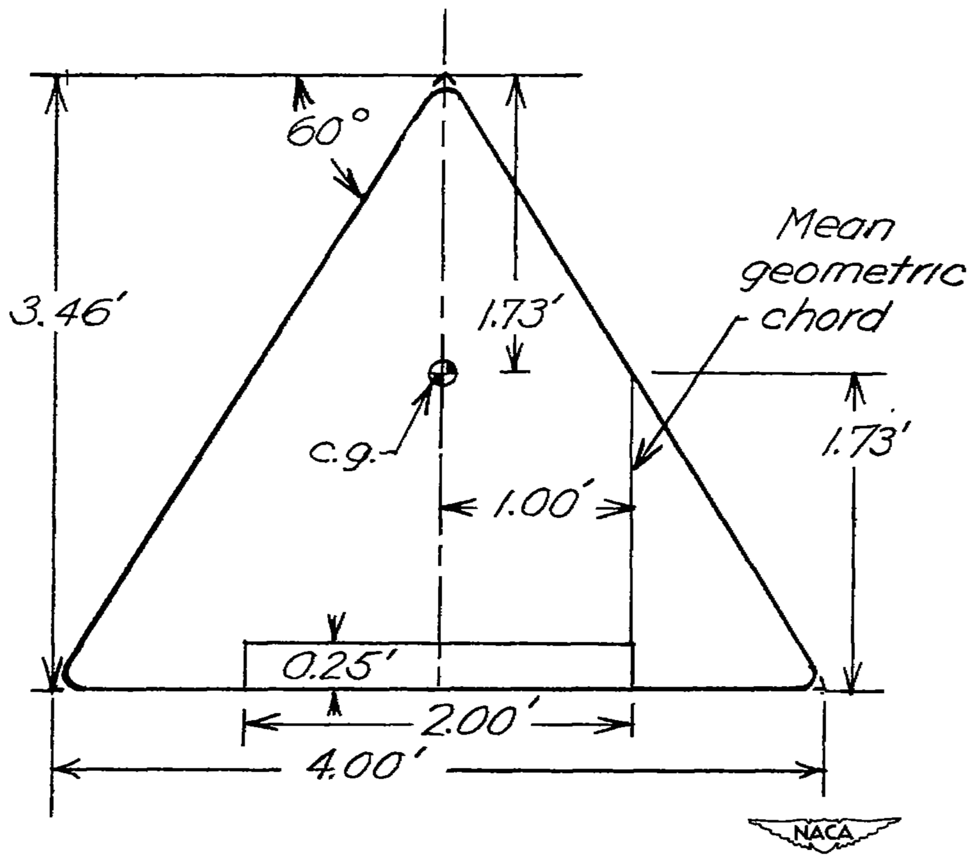



Figure 1.- Plan form of 60° delta-wing model.

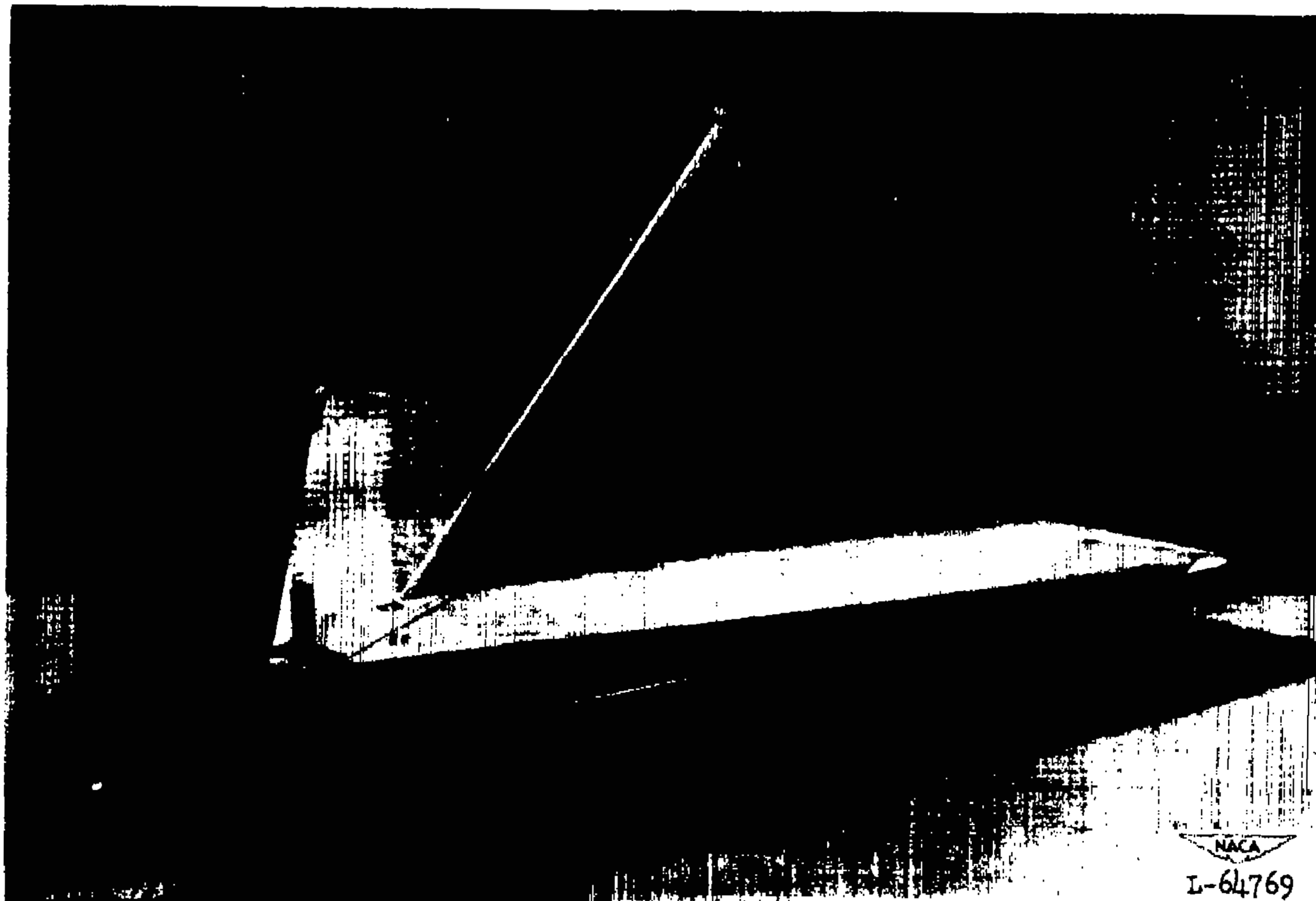



Figure 2.- Photograph of delta-wing model.

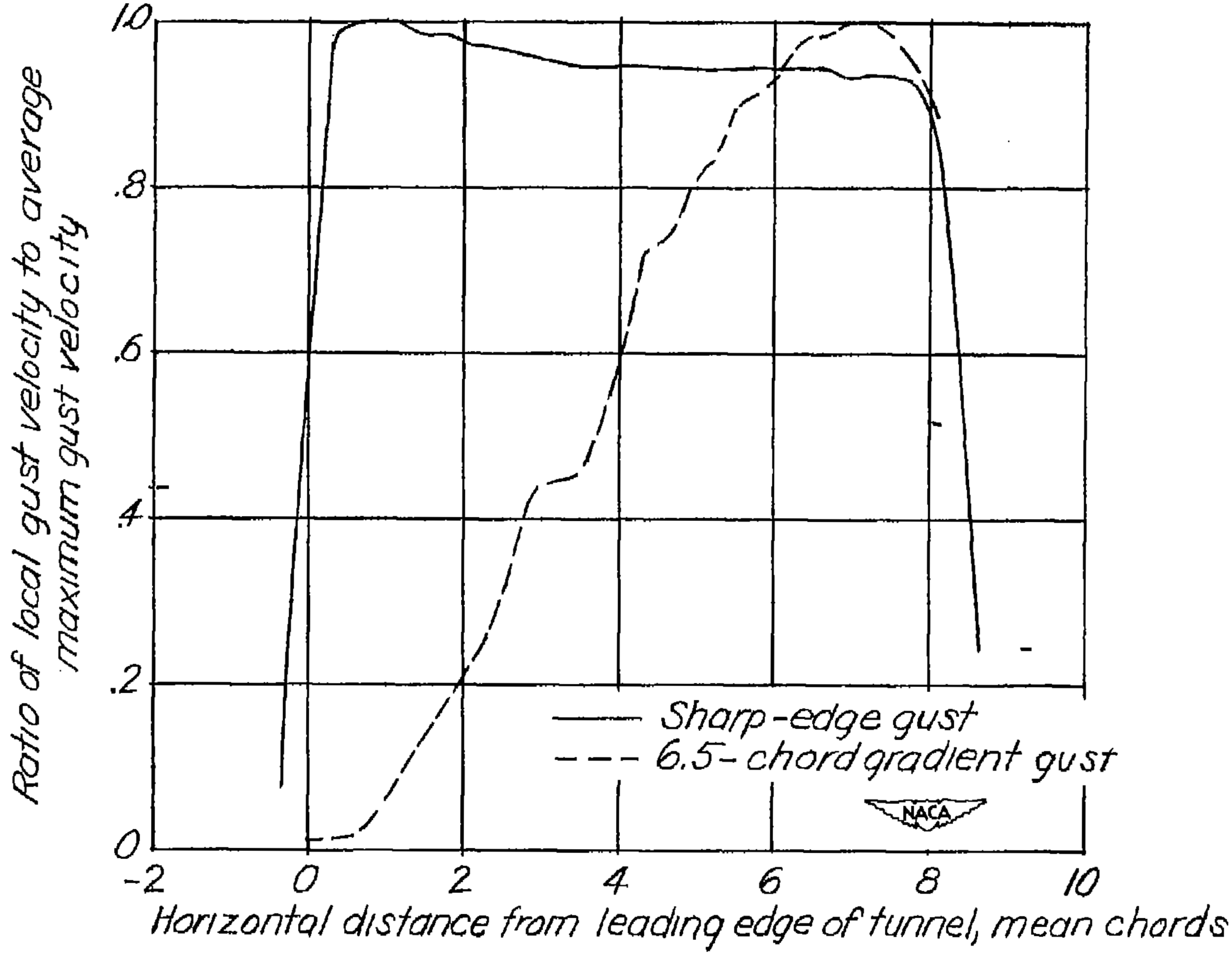
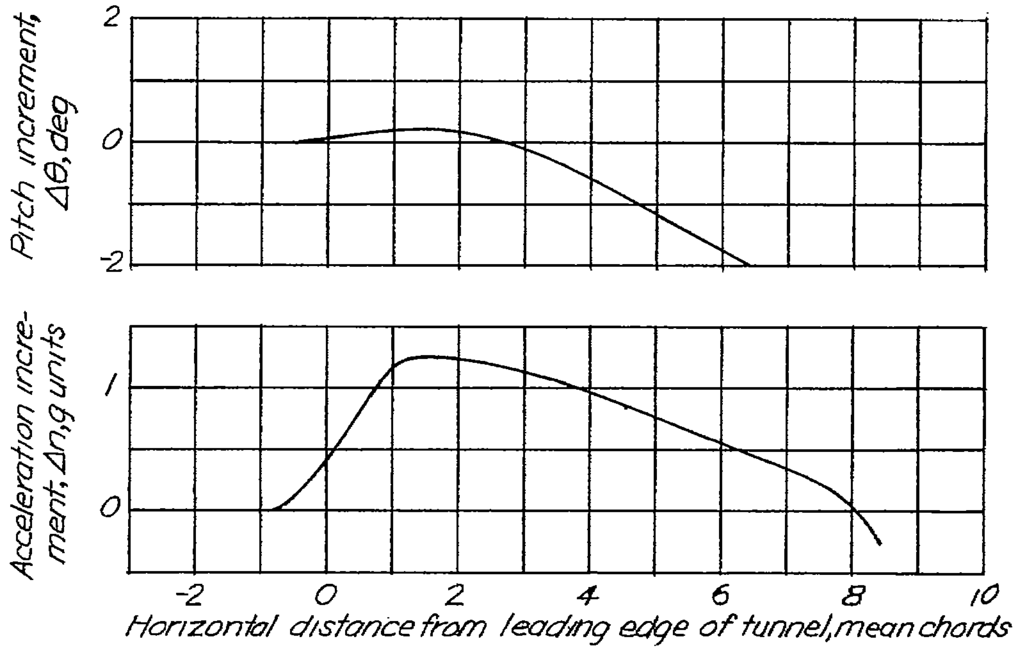
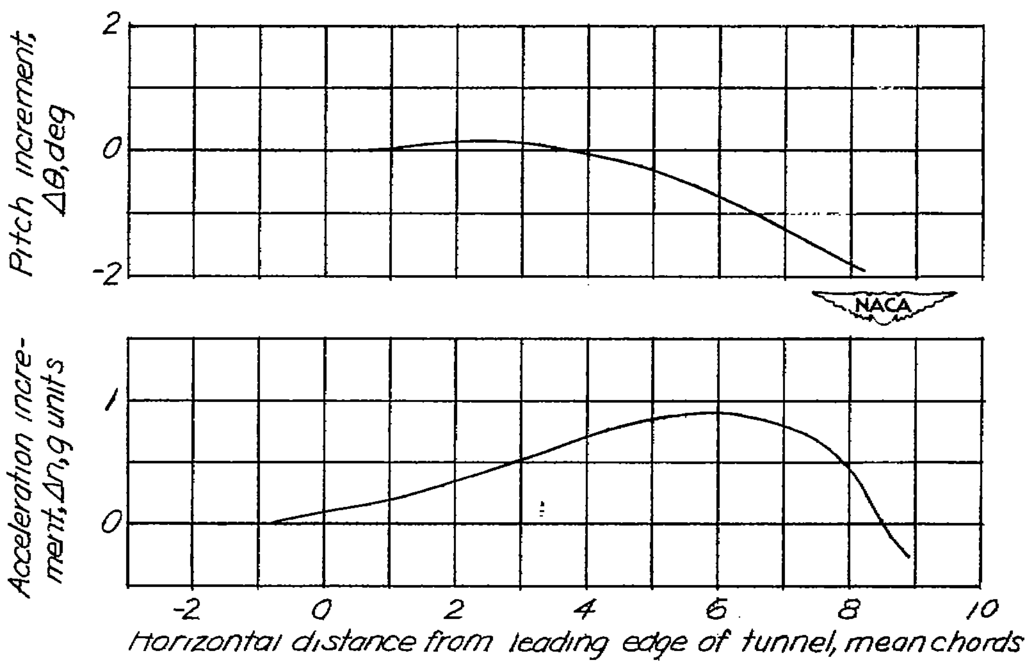



Figure 3.- Velocity distribution through gust-tunnel jet.




(a) Sharp-edge gust.




(b) Gust with 6.5-chord gradient distance.

Figure 4.- Representative history of events in test gusts.